MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2019/2020

EEE2056 – PHYSICAL ELECTRONICS

(All sections/Groups)

9 MARCH 2020
2.30 p.m - 4.30 p.m
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 6 pages with 4 Questions only.

2. Attempt **All** questions. All questions carry equal marks and the distribution of the marks for each question is given.

3. Please write all your answers in the Answer Booklet provided.

Useful constants and coefficients:

Physical Constants

Boltzmann's constant (k)	1.3807×10^{-23} JK^{-1} 8.617×10^{-5} eVK^{-1}
Planck's constant (h)	6.626×10^{-34} Js
Thermal voltage@300K kT/e kT	0.0259 V 0.0259 eV
Electron mass in free space (m_e)	9.10939×10^{-31} kg
Electron charge (e)	1.60218×10^{-19} C
Effective density of states in the conduction band for Si (N_c)	2.8×10^{19} cm^{-3}
Effective density of states in the Valence band for Si (N_v)	1.2×10^{19} cm^{-3}
Permeability of free space (μ_0)	$4\pi\times10^{-7}$ Hm^{-1}
Permittivity of free space of free space (ε_0)	8.85×10^{-12} Fm^{-1}
Avogadro's number (N_A)	6.022×10^{23} atoms/mol
Speed of light (c)	2.9979×10^{8} ms^{-1}

Question 1

(a) The time-independent Schrödinger wave equation $-\frac{\hbar^2}{2m}\frac{\partial^2\psi(x)}{\partial x^2}+V(x)\psi(x)=E\psi(x)$ is formulated based on the wave-particle de Broglie's hypothesis and the wave equation. All symbols of the equation have their usual meaning.

(i) Explain the de Broglie equation. [3 marks]

(ii) Use the Schrödinger wave equation to derive the energy of an electron in free space as a function of its momentum. [3 marks]

(iii) Sketch the energy versus momentum diagram of the electron in free space. [2 marks]

(iv) The de Broglie wavelength of an electron in free space is 125 Å. Determine the electron momentum, velocity and energy (in eV). [2+2+2 marks]

(v) With the aid of a diagram describe a type of wave can be associated with a particle. [4 marks]

(b) The Pauli Exclusion Principle states that no two electrons in a given atom may have the same set of quantum numbers namely principal quantum number n, orbital quantum number l, magnetic quantum number m_l and magnetic spin quantum number m_s.

(i) Write down the four quantum numbers for all 7 (SEVEN) electrons in an atom of Nitrogen. [4 marks]

(ii) Sketch the N atom electronic structure using a box for an orbital wave function and an arrow (up or down) for an electron. [3 marks]

Continued....

Question 2

The distribution of electrons in Gold (Au) is described by the Fermi-Dirac probability function, where electrons obeying the Pauli Exclusion Principle and conservation of energy during their interactions. Given that the Fermi energy level of Au is $E_F = 5.54$ eV at temperature of 300 K.

(a) Define the Fermi-Dirac probability function. [2 marks]

(b) Determine the probability of energy states at Fermi energy level of Au, $E = E_F$ being occupied at temperature $T = 300$ K. [2 marks]

(c) Determine the probability of an energy level at 5.58 eV being occupied by an electron at $T = 300$ K. [2 marks]

(d) Repeat (c) at $T = 600$ K. Assume that E_F is a constant. Compare the results at 300 K and 600 K, and give your comment. [3 marks]

(e) Sketch the Fermi-Dirac probability functions to discuss the effect of temperature on the distribution of electrons in Au. Include the electron distribution at 0 K in your diagram for comparison. [6 marks]

(f) Determine the speed of conduction electrons with energies around E_F in Au at 300 K. [3 marks]

(g) Determine the average thermal speed of electrons in Au at 300 K. [3 marks]

(h) Compare your answers from (f) and (g), explain why they are not the same. [4 marks]

Continued....

Question 3

(a) GaAs a direct bandgap semiconductor has an *E-k* diagram as shown in Figure Q3(a).

(i) Show that the effective mass of electron in the conduction band can be written in terms of electron energy, E and wavevector, k, as $m_e^* = \left(\frac{1}{\hbar^2}\frac{d^2E}{dk^2}\right)^{-1}$. [6 marks]

(ii) Explain why the electron effective mass is smaller than the hole effective mass in the valence band.

[3 marks]

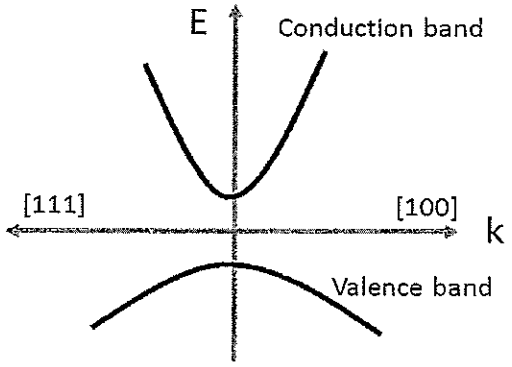

Figure 3Q(a)

(b) Sketch the *E-k* diagram of an indirect bandgap semiconductor and explain the processes of electron-hole pairs recombination in an intrinsic indirect bandgap semiconductor

[5 marks]

(c) (i) Consider an N-doped silicon with donor atoms of 2.5×10^{16} cm^{-3}. What are the concentrations of electron and hole in the silicon? Given that the intrinsic concentration, n_i = 1.5×10^{10} cm^{-3} at T =300 K. State the assumption in your calculations.

[4 marks]

(ii) Sketch the temperature dependence of electron concentration in an N-type semiconductor.

[3 marks]

(iii) At high temperatures, an N-doped semiconductor will have the characteristics of an intrinsic semiconductor. With the aid of a diagram, explain the mechanism responsible for such characteristics.

[4 marks]

Continued....

Question 4

(a) Consider a Silicon PN diode with doping density of $N_A = 2\times10^{16}\,\text{cm}^{-3}$ on the p-side and $N_D = 3\times10^{17}\,\text{cm}^{-3}$ on the n-side at T = 300 K. Given that the intrinsic concentration, $n_i = 1.5\times10^{10}\,cm^{-3}$. The built-in potential voltage V_{bi} of the diode can be expressed in terms of doping density (N_A and N_D), intrinsic carrier density (n_i) and temperature (T) in the PN junction as $V_{bi} = \frac{kT}{q}\ln\left[\frac{N_A N_D}{n_i^2}\right]$.

(i) Sketch conduction and valence energy band diagrams of the PN junction at thermal equilibrium. Briefly explain your diagrams, show clearly the Fermi level across the junction and the potential barrier. [5 marks]

(ii) Calculate the Fermi level on each side of the junction with respect to the intrinsic Fermi level and determine the height of potential barrier at the junction. [6 marks]

(iii) Determine built-in potential voltage V_{bi}. [2 marks]

(b) The typical current-voltage characteristic of a semiconductor PN junction is shown in Figure Q4 at a constant temperature.

(i) Sketch conduction and valence energy band diagrams of the PN junction under forward-biased and reverse-biased before breakdown. In your diagrams, show clearly the Fermi level in relation to the conduction and valence band edges. [4 marks]

(ii) Sketch the electron and hole distributions in the PN junction under forward- and reverse-biased. [4 marks]

(iii) Briefly explain the electron and hole currents flow across the junction under forward- and reverse-biased. [4 marks]

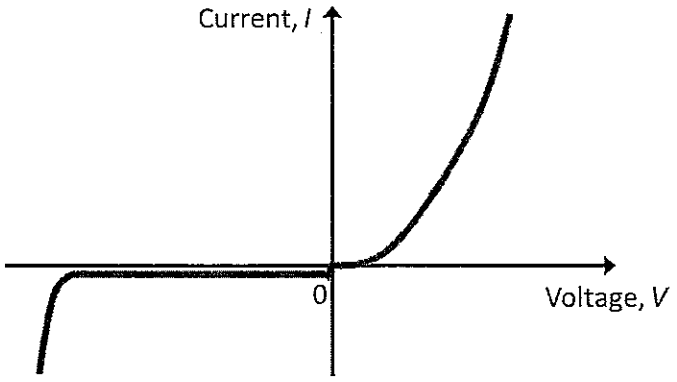

Figure Q4

End of the paper